Evaluation of local climate variability in the Peruvian Andes: an analysis of high-resolution observations and regional trends

A Senior Thesis

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with research distinction in the undergraduate colleges of The Ohio State University

by

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Table of Contents

Abstract

Rapid environmental change in the tropical Andes may have significant impacts on glacial melt rates and water resources provided by those glaciers. We analyzed a high-resolution (i.e. hourly) archive of spatially distributed climate observations from the Cordillera Blanca (8-10°S) between July 2006 and July 2010. We collected these observations using a network of Lascar Data Loggers. The network consists of nine lascars arranged throughout the Llanganuco valley. The lascars range from 3458 to 4775 meters above sea level.

Analyses of the four-year data set were conducted on three temporal scales: diurnal, seasonal, and inter-annual. Altitudinal variability was also considered. Data processing was comprised of five levels of analyses: (1) steps taken to consolidate and give confidence to the collected data; (2) a review of diurnal variability and trends; (3) a review of seasonal variability; (4) a review of inter-annual variability and trends; and (5) an evaluation of trends across elevation gradients. The evaluation of diurnal and vertical patterns between seasons was conducted in a similar fashion. These data were then compared to regional data archives for comparison.

The data collected by the lascar network in Llanganuco can be used as an input to our glacier mass balance and flow model. Providing a model to predict glacial mass balance changes can be a valuable tool for scientists and policy-makers alike in determining management practices for water resources in the Cordillera Blanca.

Acknowledgements

I am very grateful to a number of colleagues for their help and guidance with this project. Dr. Bryan Mark made my research expedition to Peru possible through his National Science Foundation (NSF) Research Experiences for Undergraduates (REU) and a grant from the Climate Water Carbon (CWC) program at The Ohio State University. For the past two years, he has been an outstanding role model as both a researcher and a man. Dr. Nathan Stansell, Kyung-In Huh, and Jeff La Frenierre were of great assistance in answering questions related to climate inputs and trends.

I would also like to thank our collaborators. Dr. Jeff McKenzie at McGill University and Dr. Jeff Bury and Adam French at the University of California-Santa Cruz provided invaluable guidance collecting data during my time in Peru. Jesús Gómez from the Peruvian Institute of Natural Resources (INRENA) was instrumental in collecting and transmitting data.

Additional funding for this research came from an Ohio State University (OSU) Arts and Sciences Undergraduate Research Scholarship, an Undergraduate Research Grant from the School of Social & Behavioral Sciences (OSU), and the G. McKenzie Undergraduate Scholarship from Byrd Polar Research Center (OSU).

List of Tables

List of Figures

Introduction

Rapid environmental change may have many serious implications. This project seeks to explore one dimension of environmental change that will impact mountain glaciers in the tropical Andes. Mountain glaciers are a critical hydrologic reservoir that helps regulate stream flow and thus water resources for many regions and people, including the populations in the Peruvian highlands.

Glaciers are important to the earth's hydrologic system, as globally they contribute approximately 4.6×10^{11} m^3/yr to the global runoff (Holland, 1978). However, in 2006, nearly 20% of the global population still lacked access to safe and affordable water for personal use (Rijsberman, 2006). The people in the arid and semi-arid regions of the world may be at risk, as Messerli estimated that over 80% of their water supply originates in mountainous regions (Messerli, 2001). The people in these regions represent greater than half of the world's population.

Continued changes in climate will drive rapid glacial retreat in the tropical Andes. Reductions in glacial volumes will have significant consequences for the people who rely on glacially derived water supplies (Bradley et al., 2006; Vuille et al., 2008). During the dry seasons and droughts, glacial meltwater provides an additional source of water, acting to buffer stream flow against the scarcity imposed by the seasonally arid climate in the tropical Andes (Mark and McKenzie, 2007). Thus, we must take action to understand and help manage their water resources, as water is one of the most basic needs for survival. Studying the dynamics of temperature changes in valleys below the glaciers in this region provides insight into hydroclimatological processes that ultimately control the mass balance of glaciers. This understanding becomes useful as water management practices are developed on a watershed scale.

The Cordillera Blanca (Figure 1), a mountain range located in the central Andes of Peru, contains approximately 70% of the world's tropical glaciers (Vuille *et al.*, 2008). The great concentration of glaciers occupy watersheds that drain to the Pacific coast and makes this an important area to study, as there are many competing demands for the water resources regulated by the glaciers. Most of the Peruvian population lives in the western part of the country along the Pacific coastal plains and western slopes of the Andes. The land in these areas is arid and heavily reliant on water runoff from the mountains (Vergara *et al.*, 2007).

Currently, little research is being done in the tropical, under-developed mountain regions (Duane, 2008), and the potential consequences of limited access to water are dire. By analyzing high-resolution climate observations, we may be able to better understand how local biophysical features and processes moderate hydroclimate, and to what extent diurnal to seasonal patterns reflect regional climate.

This case study seeks to examine a high-resolution archive of spatially distributed climate observations using lascar data loggers (Figure 3) in the Cordillera Blanca (Figure 3, 8-10°S) between July 2006 and July 2010. The lascars collect hourly measurements of temperature, relative humidity, and dew point. This study focused primarily on investigating temperature trends.

The data collected by our network of lascar data loggers in the Llanganuco valley (Figure 2) can be used as an input to our glacier mass balance and flow model.

Providing a model to predict glacial mass balance changes can be a valuable tool for scientists and policy-makers alike in determining management practices for water resources in the Cordillera Blanca.

Study Area

The Andean Cordillera Blanca is the largest and most northerly mountain range in Peru. The range covers greater than 130 km between 8°–10° south latitude, and runs northwest-southeast along the Andean continental divide. There is a distinct wet season that occurs between October and April and a dry season that lasts during the remaining months. Diurnal variability is related to the solar heating cycle. The diurnal cycle represents one of the most fundamental components of the tropical climate system. Interannual climate variability is strongly influenced by El Niño Southern Oscillation (ENSO) variability.

The Llanganuco valley is a catchment in the Cordillera Blanca located at approximately 9° south latitude. It is a U-shaped valley that was carved out by glaciers with steep walls of granodiorite bedrock that frame the mouth of the valley (Hellström, Mark and Levia, 2010). The valley drains southwest to the Santa River. This river provides more consistent monthly runoff than any of the other rivers that flow to the Pacific (Hellström, Mark and Levia, 2010), and has thus become a reliable source of water in the region.

The Huascarán summits, the tallest peaks in Peru (6,768 m above sea level), are directly to the south of the valley and form part of the southern wall. The catchment has two glacier-fed lakes near the mouth of the valley, and the valley itself has become a well-visited tourist attraction within the Huascarán National

Park and International Biodiversity Reserve. We have had to work to overcome a few obstacles related to the site as a tourist attraction, as there have been instances in which visitors have tampered with the lascar data loggers. To protect our instruments, the lascars have been surrounded in barbed wire or hidden in remote locations, and labeled as private property of The Ohio State University.

Methodology

Field Measurements

In July of 2006, a network of ten lascar data loggers (Table 1 and Figure 4) was created in the Llanganuco valley in strategic locations spanning various elevations. Within this network, there are five weather stations, each equipped with a lascar data logger, four lascar data loggers located at various altitudes on the eastern valley wall, and one lascar data logger (LLAN LOLAG) that has since been removed. The weather stations have been named LLAN CONTROL, PORTACHUELO, VAQUERIA, NORTHWALL, and HOBO AWS. The PORTACHUELO and NORTHWALL weather stations have been placed in remote locations far from human contact. The LLAN CONTROL weather station was placed near the entrance to the park in a garden by a house. The HOBO AWS weather station was placed near the lower lake, and has been surrounded by barbed wire for its protection. The VAQUERIA weather station has been placed within the grounds of a garden on the other side of the continental divide, with the residents agreeing to protect it.

The four lascars on the eastern wall have been named LLAN UP1, LLAN UP2, LLAN UP3 and LLAN UP 4. Each of these has its GPS location recorded (Table 1) and been placed out of view so as to avoid anyone tampering with the loggers. The lascars that accompany the weather stations hang underneath a hood, which serves as a radiation shield and a rain deflector. This precaution is taken because if the lascar sensors are exposed to direct sunlight, the recorded temperatures may be inflated.

The data loggers are extremely low maintenance devices, making them ideal for our purposes. Twice a year we travel to Peru to collect data (once in the wet season, and once in the dry season). Barring any damage (e.g. rockslides, human tampering, etc.) the only maintenance that the devices require is a change in battery. The lascars use one-half AA battery (3.6 volts). One of these batteries will operate the data logger for one year.

Our Peruvian collaborators assist in collecting the data, which is often helpful, but has also proved to be an obstacle. Unfortunately, we are missing some data that have either been lost (due to destruction or thievery of the lascar data loggers) or misplaced. Table 1 documents data missing from our records.

Data Analysis

Of the remaining nine lascar data loggers, temperature observations from seven were analyzed in this project, as the lascars at VAQUERIA and NORTHWALL are discontinuous from the valley transect, whereas as the other seven data loggers were more continuous (Figure 4). Analysis of the four-year data set was conducted on three temporal scales: diurnal, seasonal, and inter-annual. Altitudinal variability was also considered. My research was modeled after studies conducted by Hellström, Mark, and Levia (2010), Bumbaco (2008) and Duane, et al (2008), but focused primarily on temperature observations. The data set I analyzed is larger, and spans a longer time interval than was available for these previous studies, so this project will involve a novel and broader scale of analysis. This approach allows how local climate affects and is affected by regional and global climate trends. Nevertheless, since the predominant hallmark of tropical seasonality is the wet to dry season, I used a consistent seasonal composite analytical approach to inter-compare and extent previous results, as detailed below.

Data processing comprised of five levels of analyses: (1) steps taken to consolidate and give confidence to the collected data; (2) a review of diurnal variability and trends; (3) a review of seasonal variability; (4) a review of inter-annual variability and trends; and (5) an evaluation of trends across elevation gradients. Likewise, I adopt a similar framework for evaluating diurnal and vertical patterns between seasons.

From the data set, I selected two 24-day periods (one during the historical wet season between November and mid April, and one during the historical dry season between mid-April and October). The observations recorded between February 1st and 24th were used to represent the wet period, and the observations recorded between June 2nd and 25th were used to represent the historical dry period. These 24-day periods were chosen based on the completeness of observations and the central proximity to the historically-defined dry and wet seasons. Within these periods, I created composite hourly averages across all years to have representative dry and wet season traces to evaluate patterns over elevation.

Regional climate archives were then analyzed to inter-compare with our observational data from the Llanganuco valley. Sea surface temperature data collected from the National Oceanic and Atmospheric Administration El Nino Region 1+2 (bounded at 0.0° N, 10.0° S, 80° W, and 90.0° W) dating back to January 1990 were analyzed to determine whether oceanic temperatures impact climate in the Andes. Climate observations from the Modern Era Retrospective-analysis for Research and Applications (MERRA) dating back to January 1979 were also analyzed for comparison with the observations recorded by the network of lascar data loggers in the Llanganuco valley.

Results and Discussion

Diurnal, Seasonal and Inter-Annual Variability

The difference between the diurnal relative humidity cycles during the representative wet period and dry period illustrates a significant difference. The wet season is approximately 15% more humid throughout the course of the day. During the afternoon (12:00 – 16:00), the difference between average relative humidity values becomes more pronounced, with the wet season being approximately 25% more humid during these hours (Figure 5).

The difference between the diurnal temperature cycles during the representative wet period and dry period is not sizeable. During the late night and early morning hours (23:00 – 06:00), the wet period maintains an average of 1° Celsius average higher temperature than the dry period temperatures for that same time period. However, from the mid-morning to late-afternoon hours (08:00 – 18:00), the wet period experiences slightly cooler temperatures than the dry period

(Figure 6a). This difference in temperature observations is likely due to increased cloud cover during the wet season, as clouds help keep the earth's surface relatively warmer overnight, and cooler during the day, whereas temperatures fluctuate more during the dry period due to less cloud cover.

We have found that the average day during the wet period only is 0.2°C warmer than the dry period. This is not consistent with the 1°C cooler wet period temperatures derived from the single-year archive analyzed by Hellström. However, it is consistent with the findings derived from multi-year records analyzed by Juen, et al. (2007), who were able to determine that temperatures were 1°C warmer during the wet period than during the dry period in nearby locations. It appears that since Hellström's study investigated climate observations over the course of only one year, 2005-06, that this study may have been conducted during an anomalous year.

In general, there was greater inter-annual variability in the diurnal cycle during the wet season than during the dry season (Figures 6b and 6c, Appendix). 2007 and 2010 feature higher wet season average temperatures from each data logger than the other years in the archive, and 2009 yielded lower wet season average temperatures from each data logger than any other year in the archive. Inter-annual variability in the diurnal cycle during the dry season was much less pronounced than the variability illustrated during the wet season.

Seasonal and Inter-Annual Trends Across Elevational Gradients

When inter-comparing the average temperature during the diurnal cycle, it became apparent that temperatures decreased as elevations increase. For further analysis, temperature averages were re-organized to evaluate the measurements across an elevational gradient. This created the average daily vertical temperature profile. This daily vertical temperature profile was aggregated into a diurnal cycle that limited to measurements on intervals of every three hours rather than on an hourly basis (Figures 7 & 8). These figures also include the average lapse rates calculated from the MERRA data.

This temperature profile revealed inflections between 3833 and 3458 m above sea level that likely result from the two lakes acting as heat sinks, releasing heat in the night and early morning hours (18:00 – 06:00). Another inflection can be seen in the temperature profile where temperatures between 3955 and 4355 meters above sea level are cooler than the other elevations. This decrease in average temperatures could be the result of katabatic winds coming off of the north face of Huascarán bringing cold air to the area surrounding those three lascar data loggers. These occur in both the wet and dry seasons, but the temperatures varied more during the dry season. It is also possible that the station LLANUP 4 is anomalously warmed in the afternoon due to exposure to direct insolation.

The near surface lapse rate was determined by averaging the hourly temperature measurements at each elevation for the dry and wet periods, and computing the slope of linear trend line (Figures 9 & 10, Table 2). These lapse rates were used to extrapolate the estimated freezing height, or the elevation above which the average temperature is below freezing.

The calculated lapse rate indicates that on average, the freezing heights are only 5 meters higher during the wet period than during the dry period. This contrasts Hellström's study, which showed a 240-meter increase in the freezing height during the wet season from the dry season. This illustrates that the average seasonal difference in freezing heights is very small, which is consistent with the small difference in average seasonal temperatures.

Regional Monthly Temperature Anomalies

Data analyses were conducted on two other data sets in order to compare the Llanganuco local temperature regime to regional patterns and trends. Sea surface temperature data archived at the National Oceanic and Atmospheric Administration (NOAA) were analyzed from the El Niño Region 1+2 (Figure 11) to determine whether oceanic temperatures impact climate in the Andes, and to consider specifically if the ENSO phenomenon drives climate in the Llanganuco valley. Atmospheric temperatures from the Modern Era Retrospective-analysis for Research and Applications (MERRA) were also analyzed for comparison with the observations recorded by the network of lascar data loggers in the Llanganuco valley. The MERRA data were collected from the grid (bounded at 8°07'48"S, 10°37'30"S, 78°07'30"W and 76°51'49" W) that overlaps most of the Cordillera Blanca (smaller rectangle in Figure 11). These continuously output data are assimilated on a global scale from numerical models and provide a means to evaluate how our local scale observations capture larger scale dynamics.

The ENSO phenomenon has a strong effect on Perú and its neighboring countries. Since 1990, there have been two moderate El Niño years (1994 and 2002), three strong El Niño years (1991, 1997, and 2009), four moderate La Niña years (1998, 1999, 2007, and 2010), and no strong La Niña years (Table 3). El Niño years are defined as years when five consecutive months have experienced a greater than +0.5° C anomaly in Pacific SSTs. La Niña years are defined as years when five consecutive months have experienced a greater than -0.5° C anomaly. Moderate events occur when the anomaly is +/-1.0 to +/-1.4° C and Strong events occur when the anomaly is greater than +/- 1.5° C (Golden Gate Weather Services, 2011).

El Niño years are associated with: (a) below normal rainfall in the Andes, (b) above normal precipitation over the southeastern portion of the continent and central Chile, and (c) warmer than normal conditions over tropical and subtropical latitudes. Opposite rainfall and temperature anomalies are observed during La Niña episodes. Cold air anomalies during El Niño events are observed over mid-latitudes during spring, likely because an ENSO-related increase in rainfall is also associated with a reduction of insolation and moistening of the surface.

Figure 12 depicts the relationship between SSTA recorded by NOAA and the MERRA data, and temperature anomalies correspond with each other during the El Niño and La Niña years. When examining Figure 13, there appears to be an inverse relationship between Pacific SST anomalies and near land-surface temperature anomalies recorded in Llanganuco and the MERRA reanalysis. This might be explained by the ENSO-related increase in rainfall that is associated with reduced insolation and a more moist land surface. Both of these observations support the conclusions drawn in the Garreaud study (Garreaud, *et al.* 2009).

Conclusions and Future Work

Through this research, I was provided an opportunity to analyze a data set of unprecedented length and resolution for its geographic location. We were able to confirm that the seasonal cycle represents one of the most fundamental components of the tropical climate system. We observed that within the valley, there exists a heat source that oscillates throughout the course of the day. It is likely that this heat source is in fact the two lakes in the valley. This heat source could promote local convection and other complex climate processes seen in seasonal and diurnal lapse rates. Continuing this research by maintaining the lascar data logger network in the Llanganuco valley will allow better evaluation of local climate variability and the implications related to anthropogenic climate change. Further analyses of the data set will inform predictive models illustrating potential local impacts of climate change.

This project addresses an issue that has broad consequences for an entire region. Life depends on water, and the current retreat of the glaciers in the central Peruvian Andes is transforming the surface water availability that is used for irrigation, potable water, and hydroelectric generation. Our ongoing research to gain an understanding of the climate dynamics that influence the hydrologic cycle is important to better inform assessments of social vulnerability. Once we gain a better understanding the climate processes and dynamics that alter the hydrologic cycle, we can evaluate adaptation, mitigation, or even geo-engineering responses to future changes with a view to actual livelihoods of all the people relying on glaciers as a water resource.

This implies that there is still much work to be done. While work done through the course of this research project, this has been the initial steps to continued work to provide a model to predict glacial mass balance changes can be a valuable tool for scientists and policy-makers alike in determining management practices for potentially scarce water resources in the Cordillera Blanca.

References

Bradley, R., Vuille, M., Diaz, H., and Vergara, W. "Threats to Water Supplies in the Tropical Andes." *Science,* 312 (2006): 1755-1756.

Bumbaco, K. (2008). Seasonal and Diurnal Variations in Hydrometeorological Variables in an Andean Mountain Environment and Comparison to the NCEP/NCAR Reanalysis I Data. (Unpublished Masters Thesis). The Ohio State University, Columbus, Ohio.

Duane, W. et al. "General Characteristics of Temperature and Humidity Variability on Kilimanjaro, Tanzania." *Arctic, Antarctic, and Alpine Research*. 40.2 (2008): 323-334.

Golden Gate Weather Services (2011, May 5). El Niño and La Niña Years and Intensities. Retrieved May 7, 2011, from http://ggweather.com/enso/oni.htm

Hellström, R., Mark, B., and Levia, D. "Seasonal and Diurnal Fluctuations of Boundary Layer Conditions Within a Tropical Alpine Valley in the Peruvian Andes: Implications for Evapotranspiration." Submitted to *Quarterly Journal of the Royal Meteorological Society*. (2010): 1-36.

Holland, Heinrich D. *The Chemistry of the Atmosphere and Oceans*. New York: Wiley, 1978.

Juen I., Kaser, G., Georges C. “Modelling observed and future runoff from a glacierized tropical catchment.” *Global and Planetary Change*. 59 (2007): 37-48.

Mark, B., and McKenzie, J. “Tracing Increasing Tropical Andean Glacier Melt with Stable Isotopes in Water.” *Environmental Science & Technology* 41.20 (2007): 6955-6960.

Messerli, B. The International Year of the Mountains, the Mountain Research Initiative, and PAGES editorial. *Past Global Changes News,* 9 (2001): 2.

NASA’s Global Modeling and Assimilation Office. (2009) [Data file] Retrieved from http://gmao.gsfc.nasa.gov/research/merra/data_access.php

National Oceanic and Atmospheric Administration. (2011). *Nino 1+2* [Data file]. Retrieved from http://www.cpc.ncep.noaa.gov/data/indices/

Rijsberman, F. “Water Scarcity: Fact of Fiction?” *Agricultural Water Management, 80* (2006): 5-22.

Vergara, W., Deeb, A., Valencia, A., Bradley, R., Francou, B., Zarzar, A., Grunwaldt, A., Haeussling, S. “Economic impacts of rapid glacial retreat in the Andes.” *Eos, Transactions American Geophysical Union*, 88 (2007): 261-263.

Vuille M. and Bradley R. “Mean annual temperature trends and their vertical structure in the tropical Andes.” *Geophysical Research Letters.* 27.23 (2000): 3885-3888.

Vuille M. et al. “Glacier mass balance variability in the Cordillera Blanca, Peru and its relationship with climate and the large-scale circulation.” *Global and Planetary Change.* 62 *(*2008): 14-28.

Tables

Table 1: GPS locations of lascar data loggers in the Llanganuco valley and Vaqueria.

Name	Longitude	Latitude	Elevation
LLAN CONTROL	-77.6832	-9.10603	3458
HOBO AWS	-77.6512	-9.07943	3833
LLAN LOLAG	-77.6427	-9.07162	3846
LLAN UP1	-77.6093	-9.04958	3955
LLAN UP2	-77.5994	-9.05432	4122
LLAN UP3	-77.5972	-9.04847	4355
LLAN UP4	-77.5977	-9.04355	4561
PORTACHUELO	-77.5906	-9.05000	4775
VAQUERIA	-77.5242	-9.00638	3493
NORTHWALL	-77.6440	-9.05923	4544

Table 2: Inter-annual and seasonal comparison of lapse rates and freezing heights

	Lapse Rate (degrees Celsius per kilometer)		
	Wet Season	**Dry Season**	**Yearly Average**
2007	6.53	9.36	7.7
2008	6.59	5.31	5.9
2009	5.58	5.9	5.9
2010	5.44	5.4	5.5
	Freezing Heights (meters above sea level)		
	Wet Season	**Dry Season**	**Yearly Average**
2007	5199.5	4956.8	5073
2008	5109.3	5324.9	5216.7
2009	5142.7	5232.9	5153.8
2010	5488	5401.6	5426.6

Table 3: List of El Niño and La Niña events since 1990

El Niño Event		**La Niña Event**	
Strong Year	**Moderate Year**	**Strong Year**	**Moderate Year**
1991	1994		1998
1997	2002		1999
2009			2007
			2010

Figures

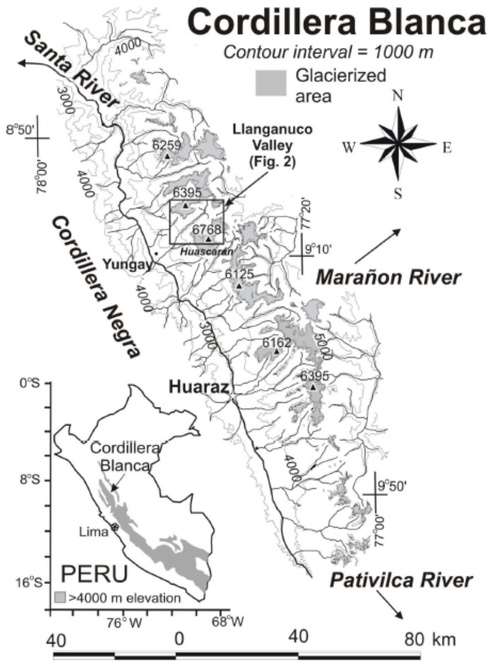


Figure 1: Cordillera Blanca regional map.

Figure 2: Southwest-looking view of the Llanganuco valley from the Portachuelo pass.

Figure 3: Lascar data logger "LLAN UP3" in the field with its protective hood.

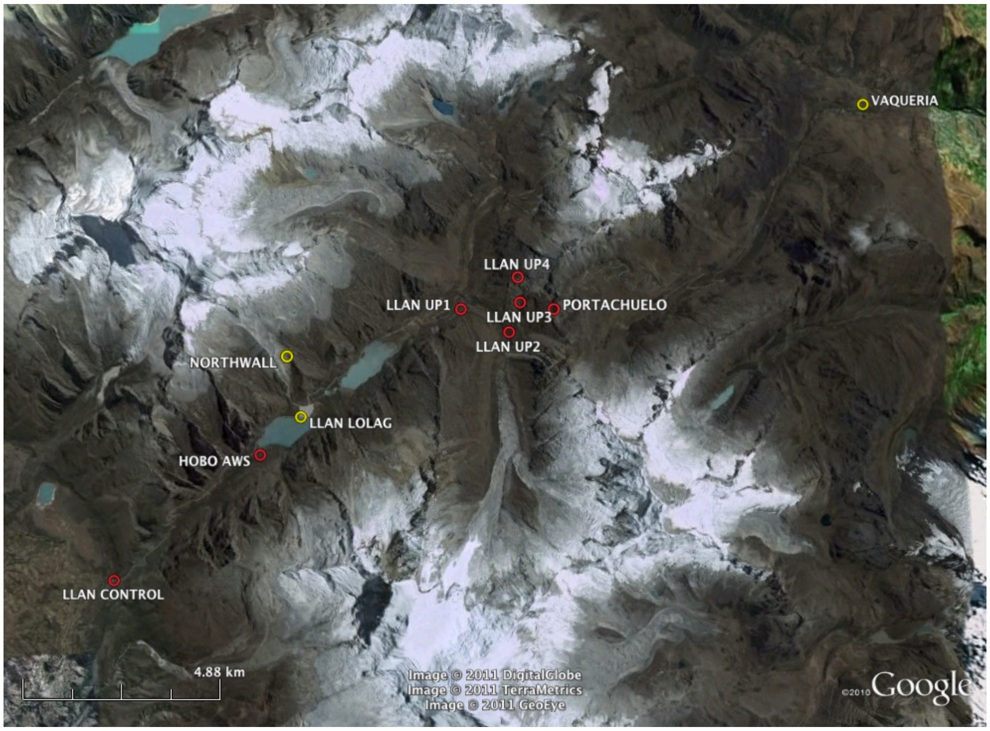


Figure 4: Map of lascar data loggers by GPS location in the Llanganuco valley and Vaqueria. The red circles indicate the lascars that were used during this research project.

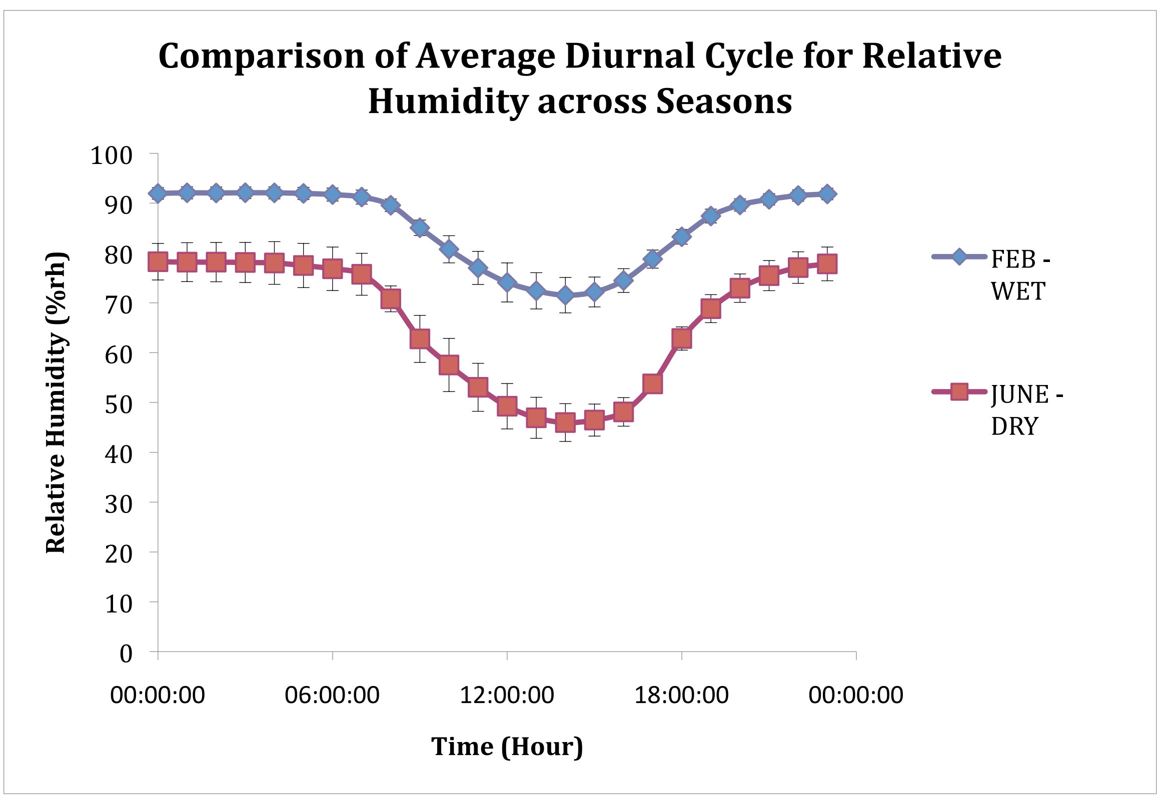


Figure 5: Seasonal variability of diurnal relative humidity cycles and the standard deviation

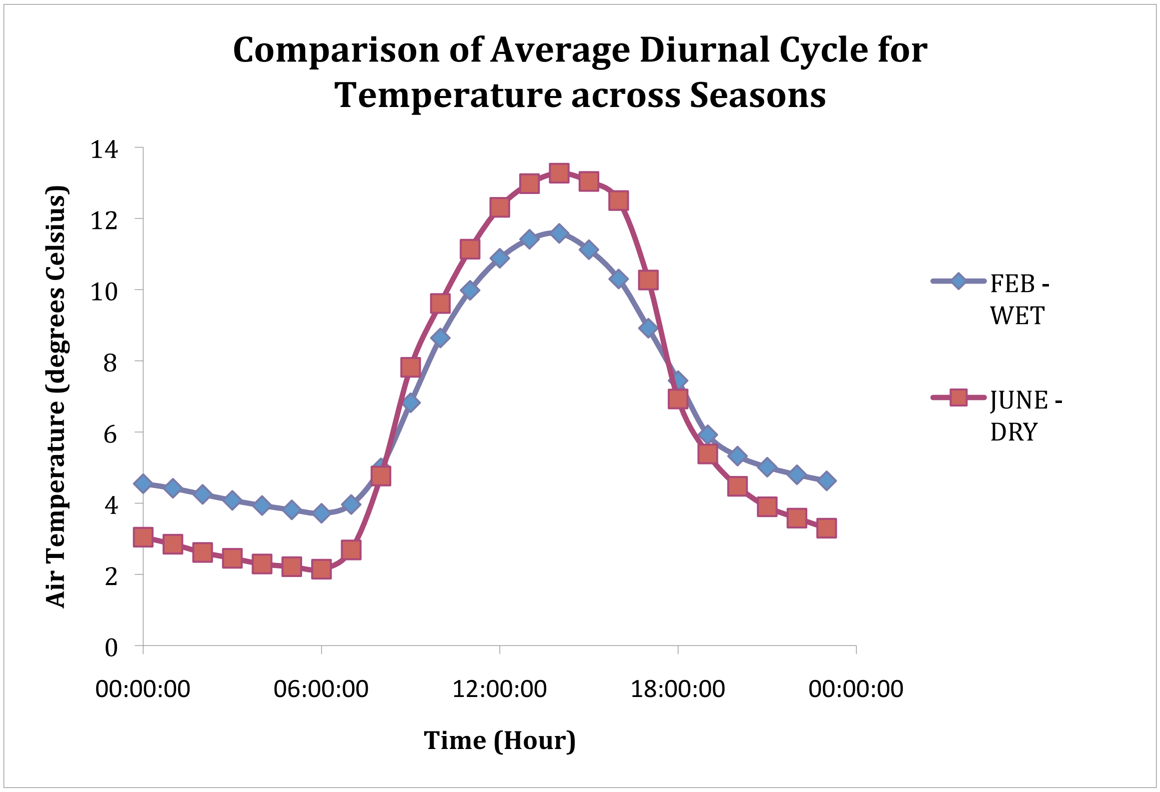


Figure 6a: Seasonal variability of diurnal air temperature cycles

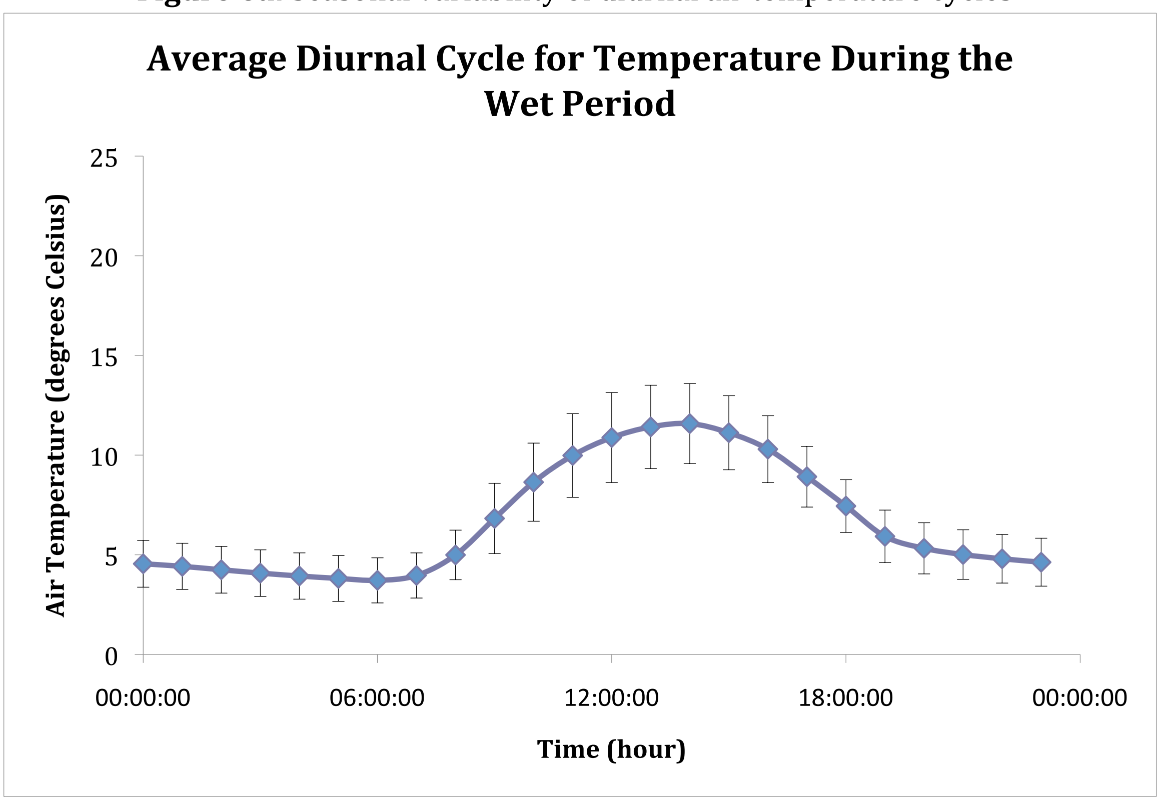


Figure 6b: Wet period diurnal cycle with standard deviation error bars

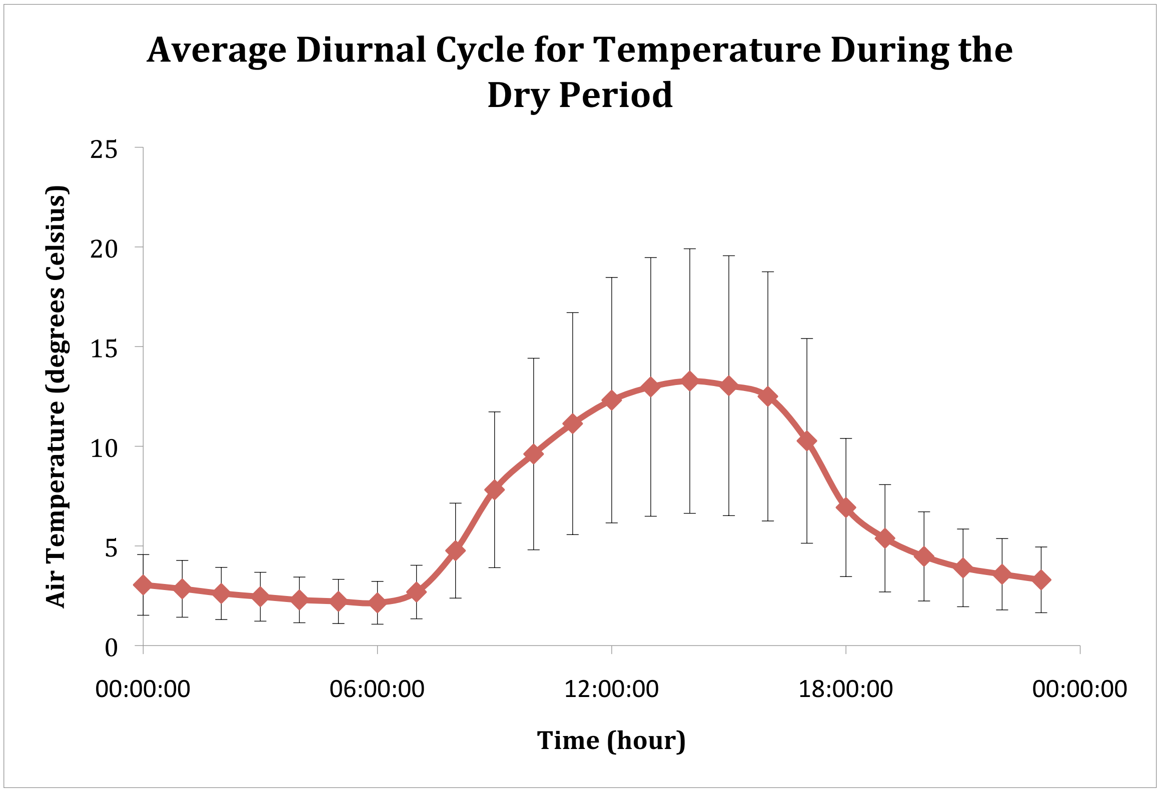


Figure 6c: Dry period diurnal cycle with standard deviation error bars

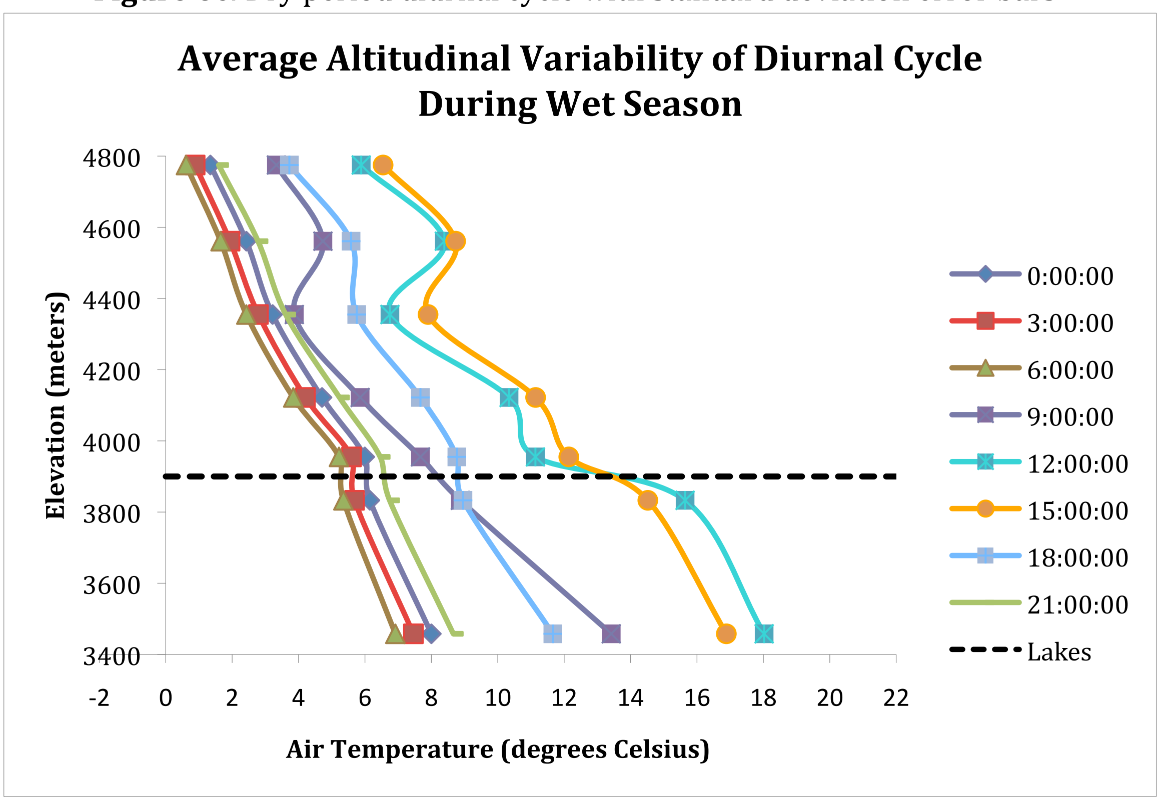


Figure 7: Wet period average near surface air temperature at three-hourly intervals

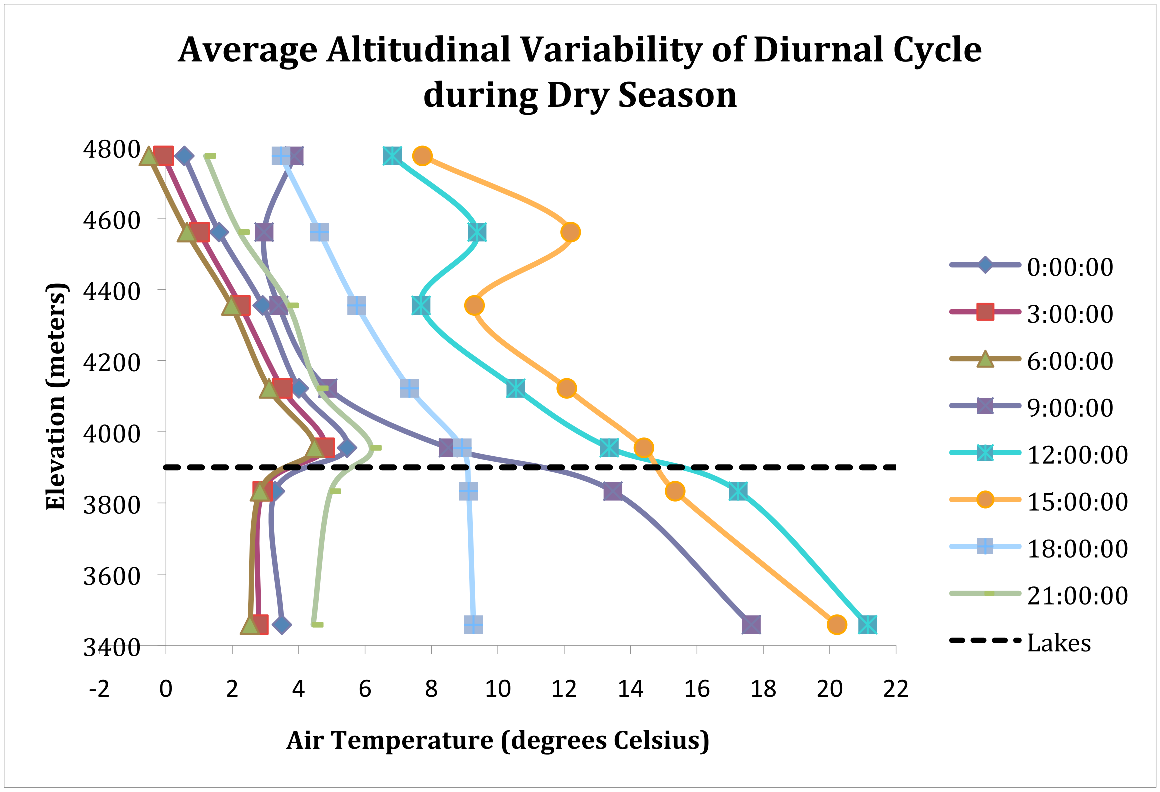


Figure 8: Dry period average near surface air temperature at three-hourly intervals

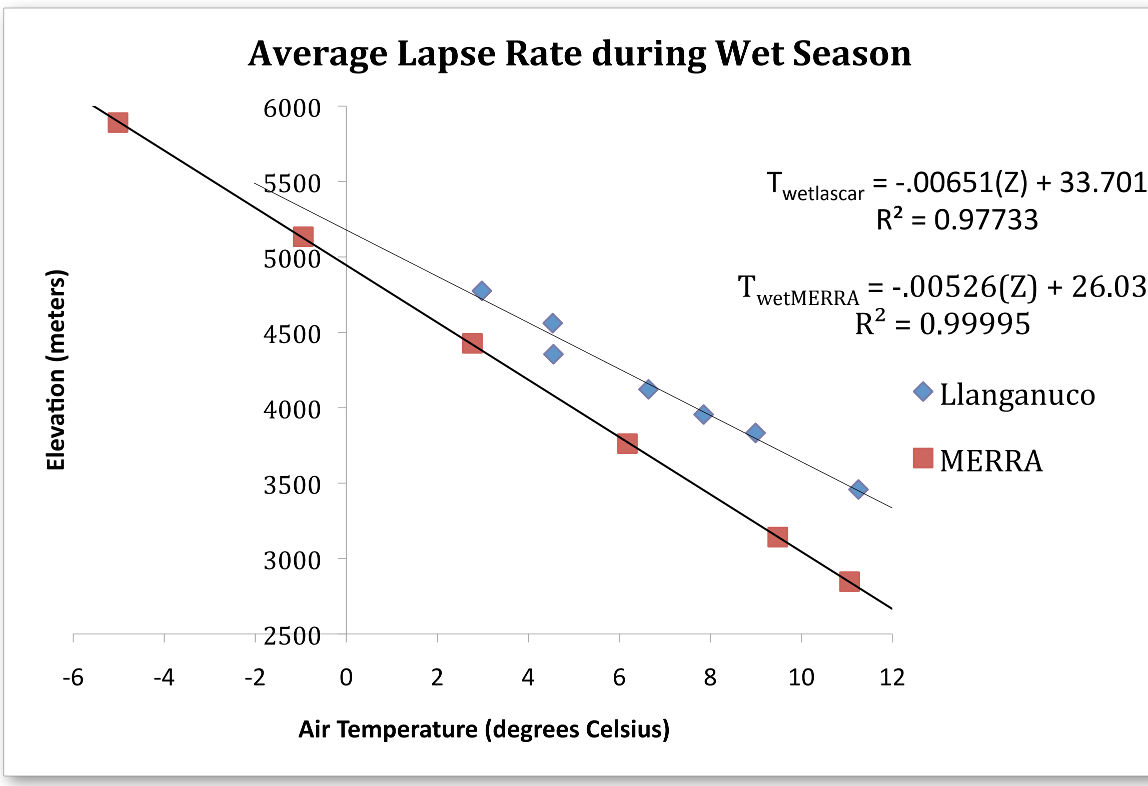


Figure 9: Average daily temperature profile (near surface lapse rate) for wet season.

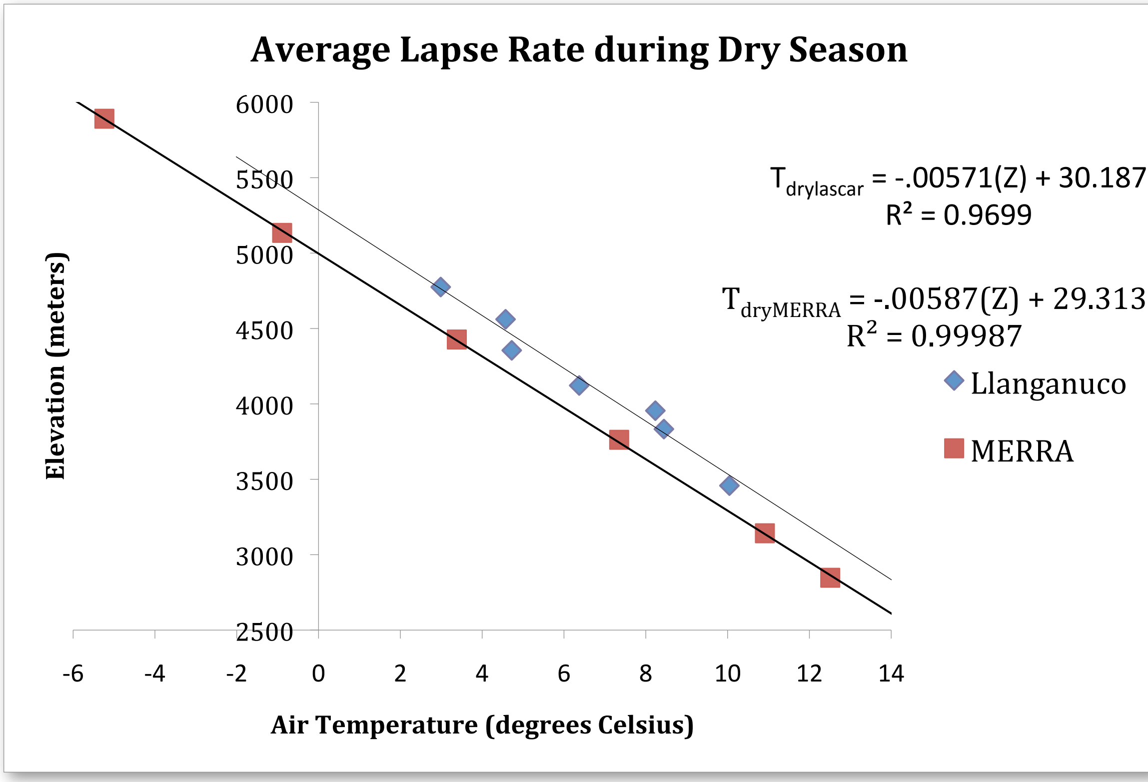


Figure 10: Average daily temperature profile (near surface lapse rate) for dry season.

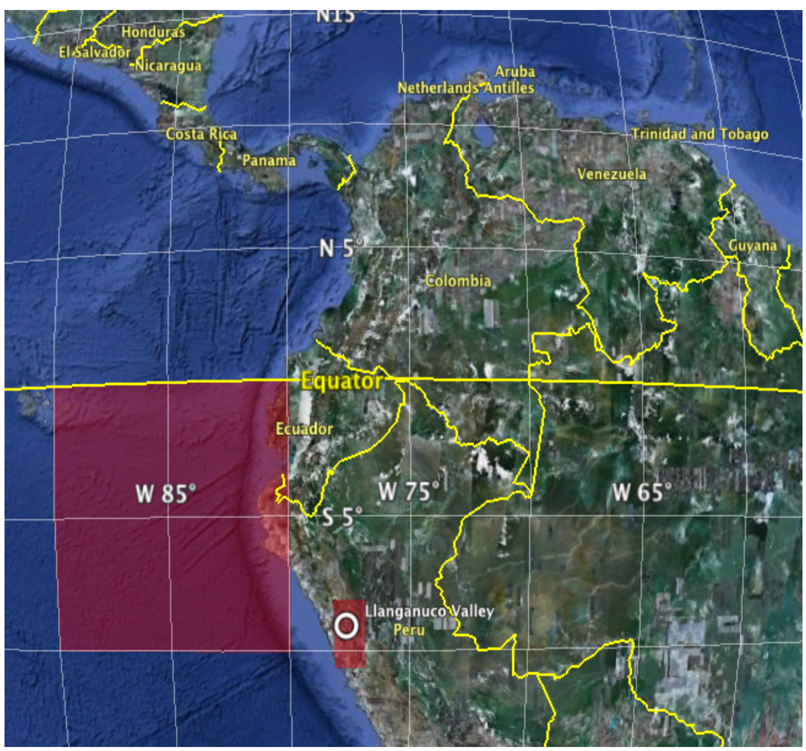


Figure 11: Map of regions covered by NOAA SSTs (large rectangle) and MERRA data (smaller rectangle).

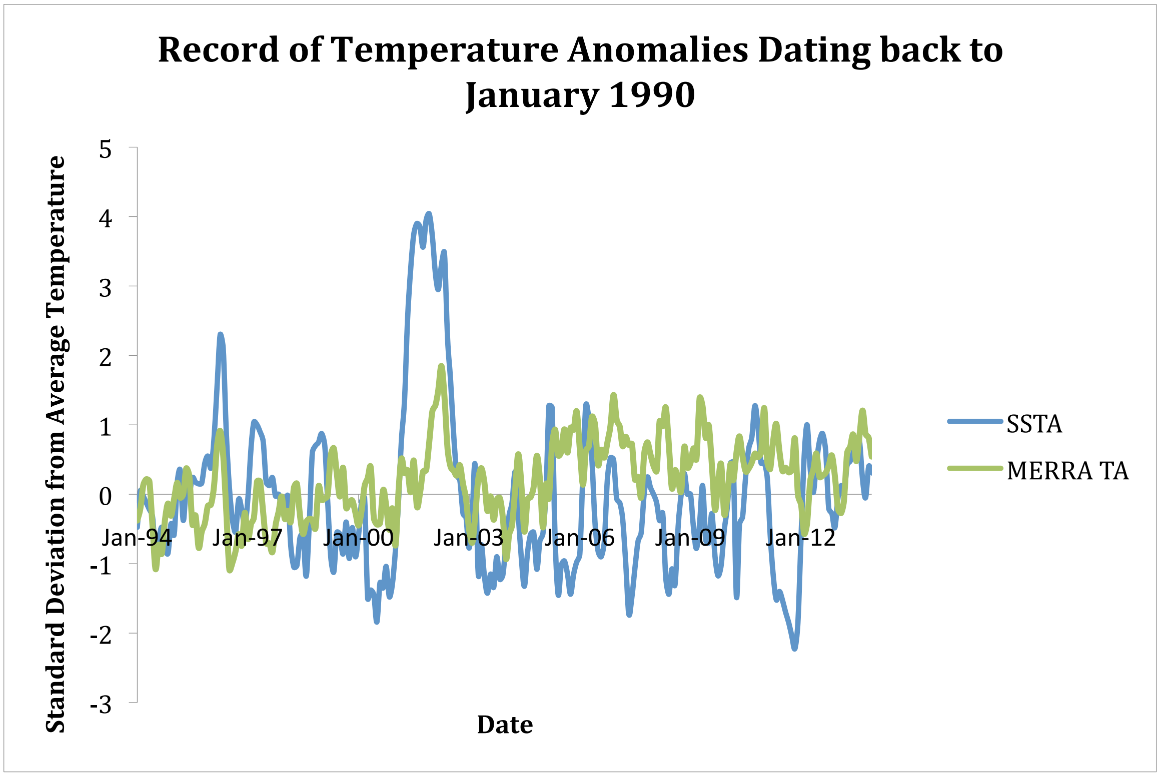


Figure 12: Monthly regional temperature anomalies dating back to 1990.

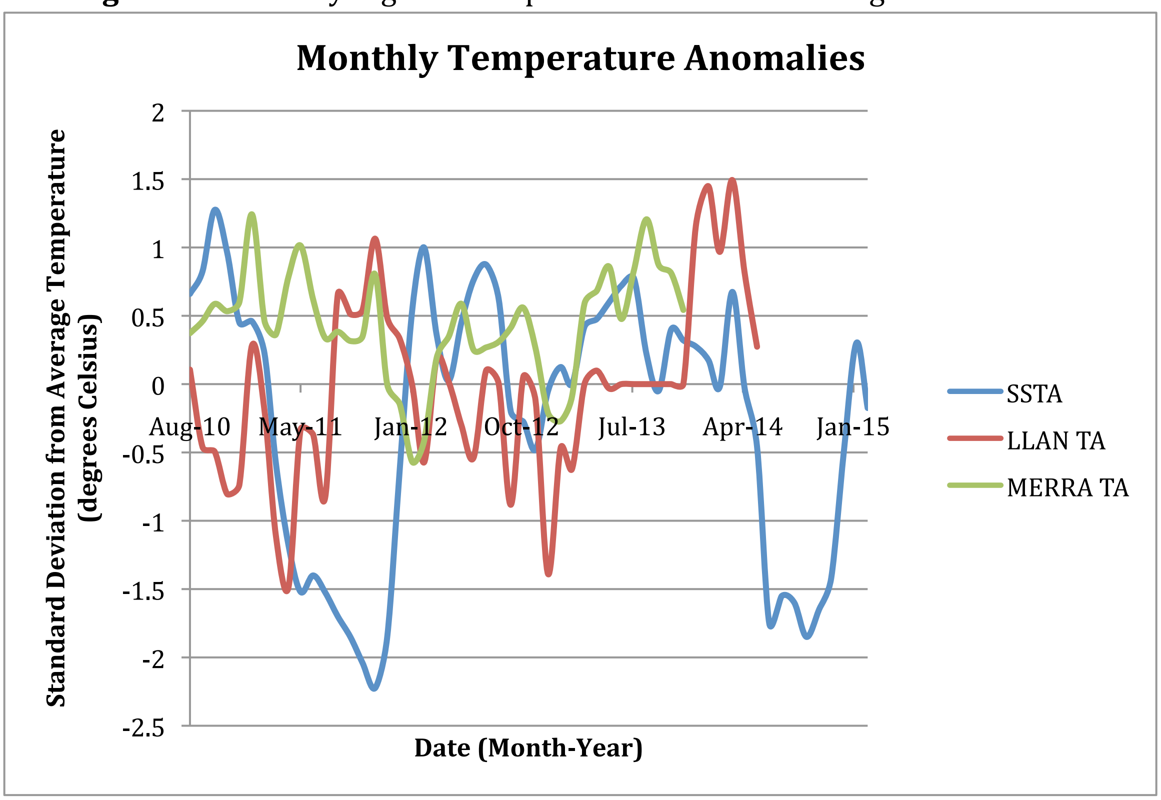
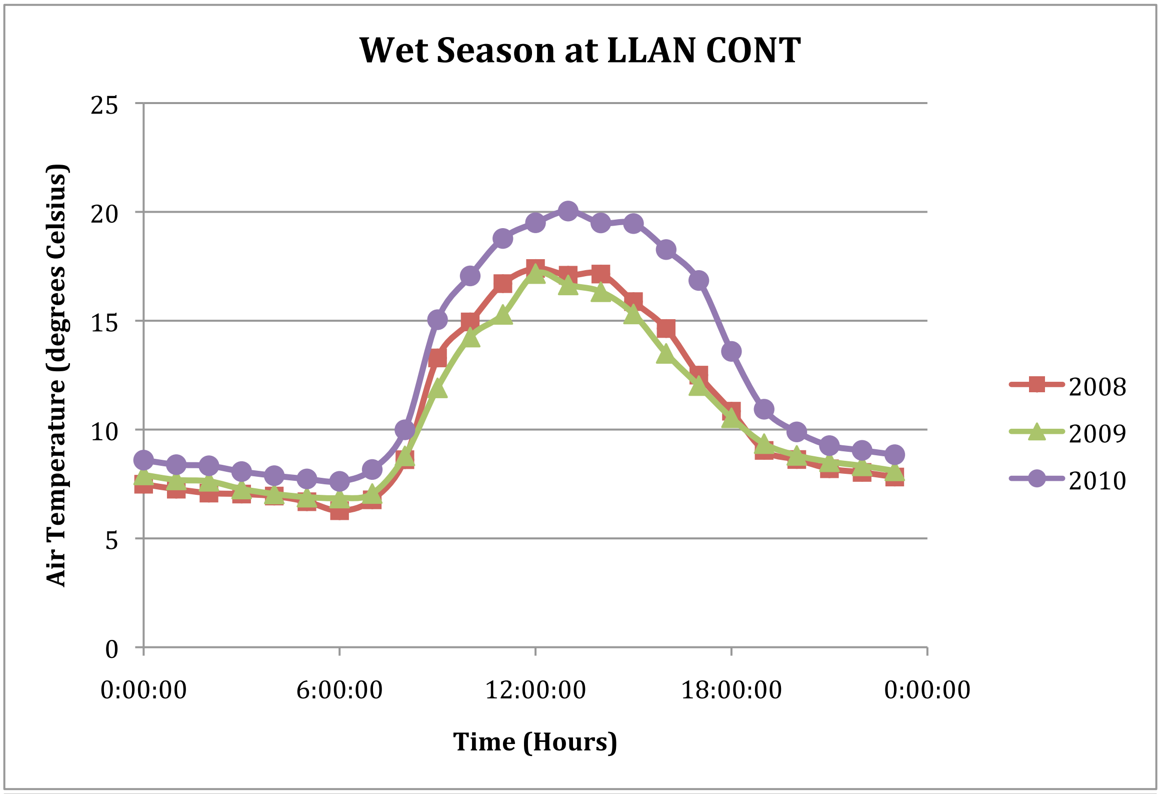
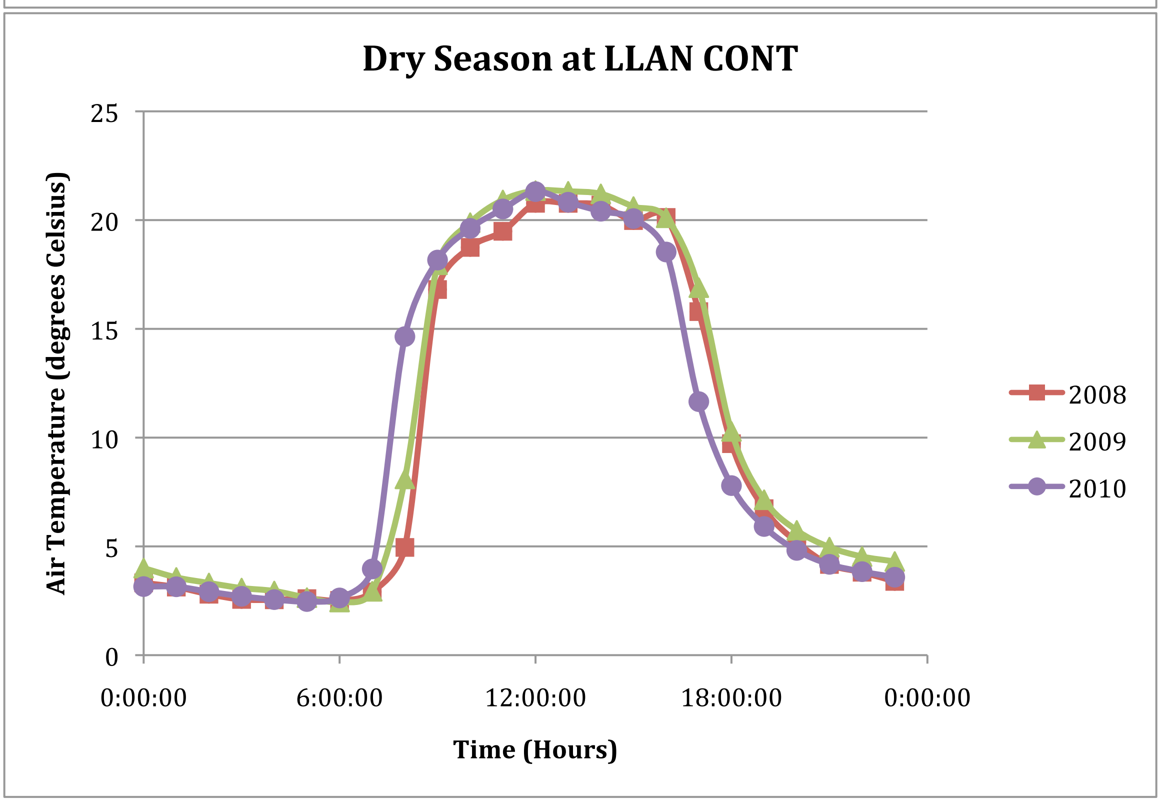
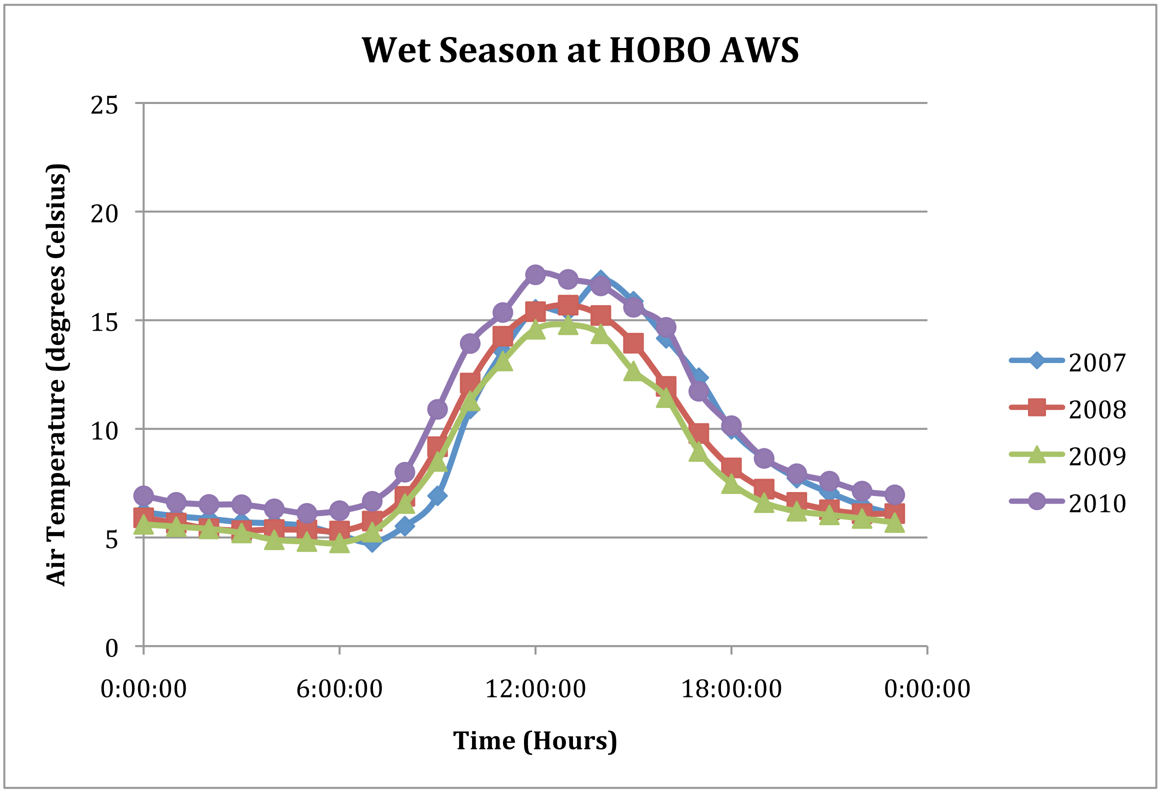


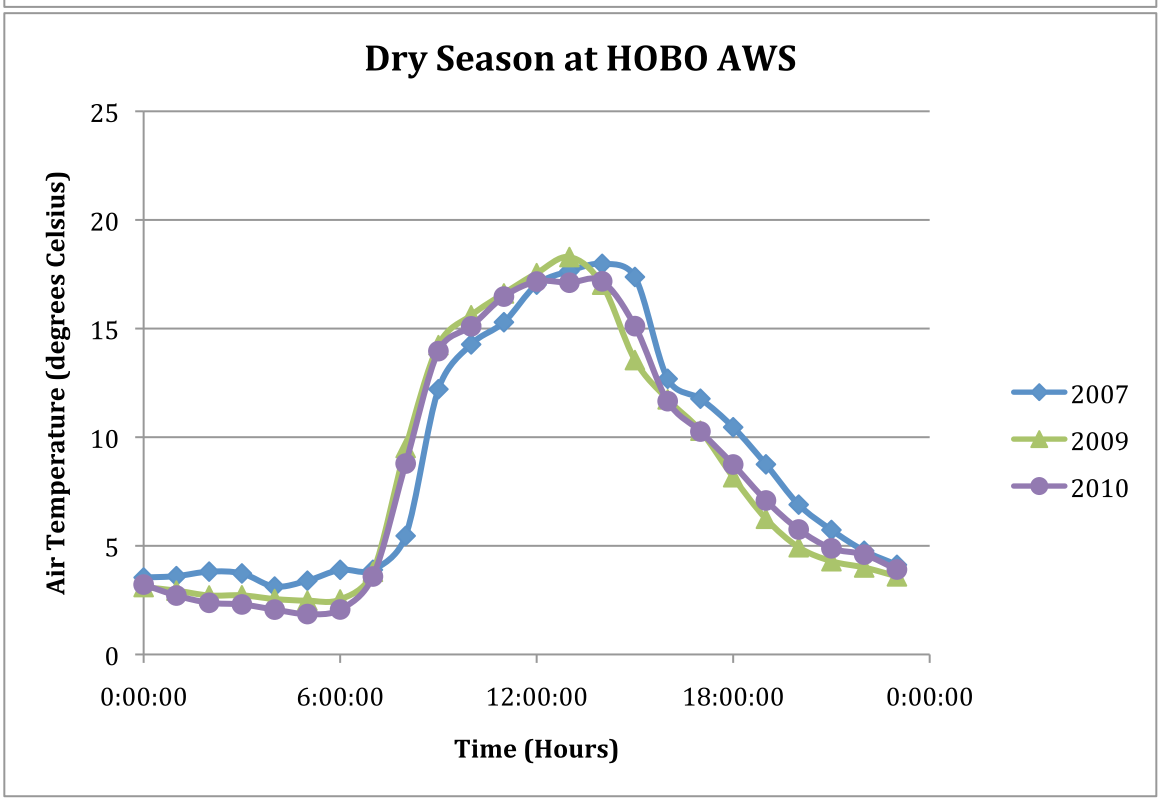
Figure 13: Monthly regional temperature anomalies during the study period from August 2006 to March 2011.

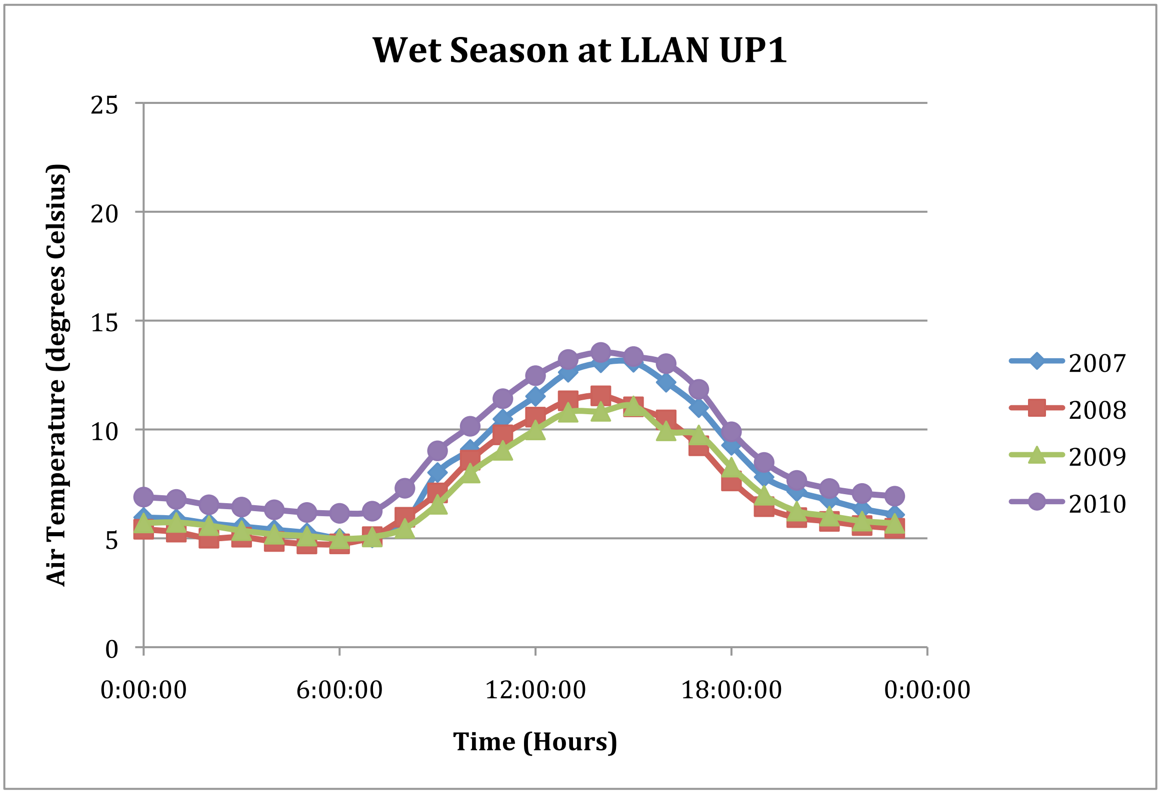
Appendix: Inter-annual Variability of the Diurnal Temperature Cycle

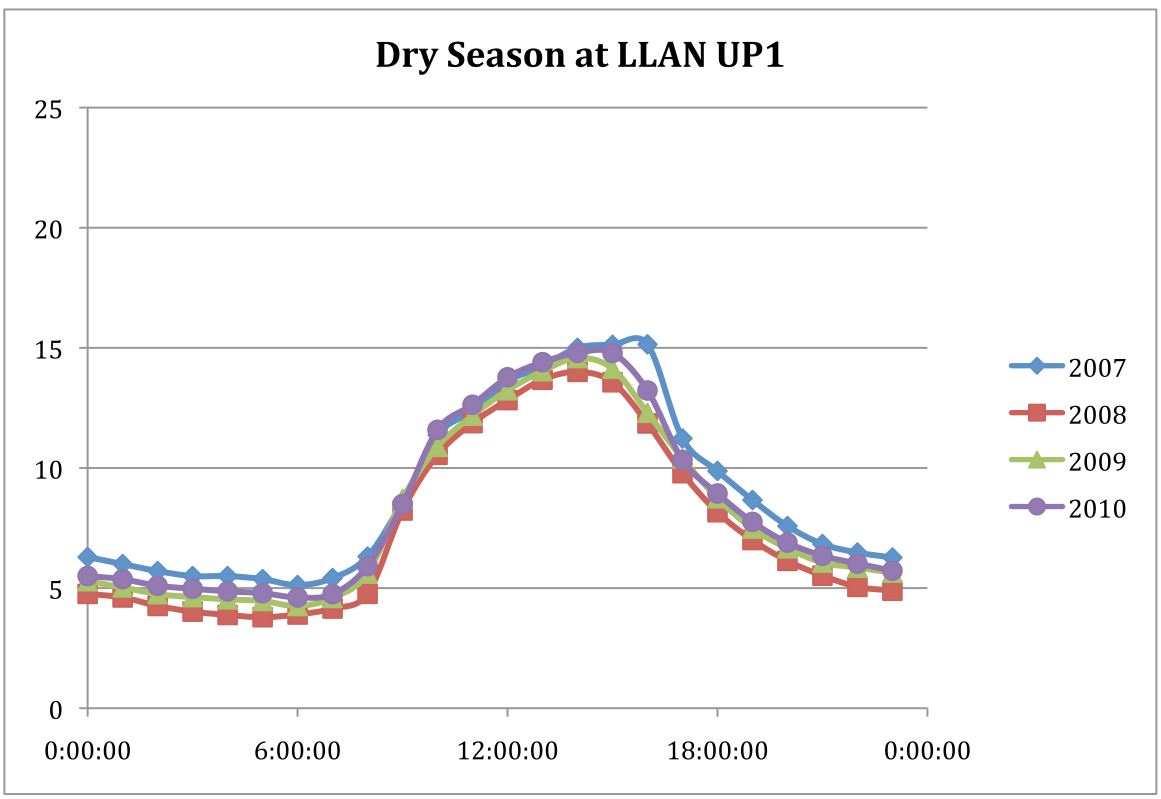


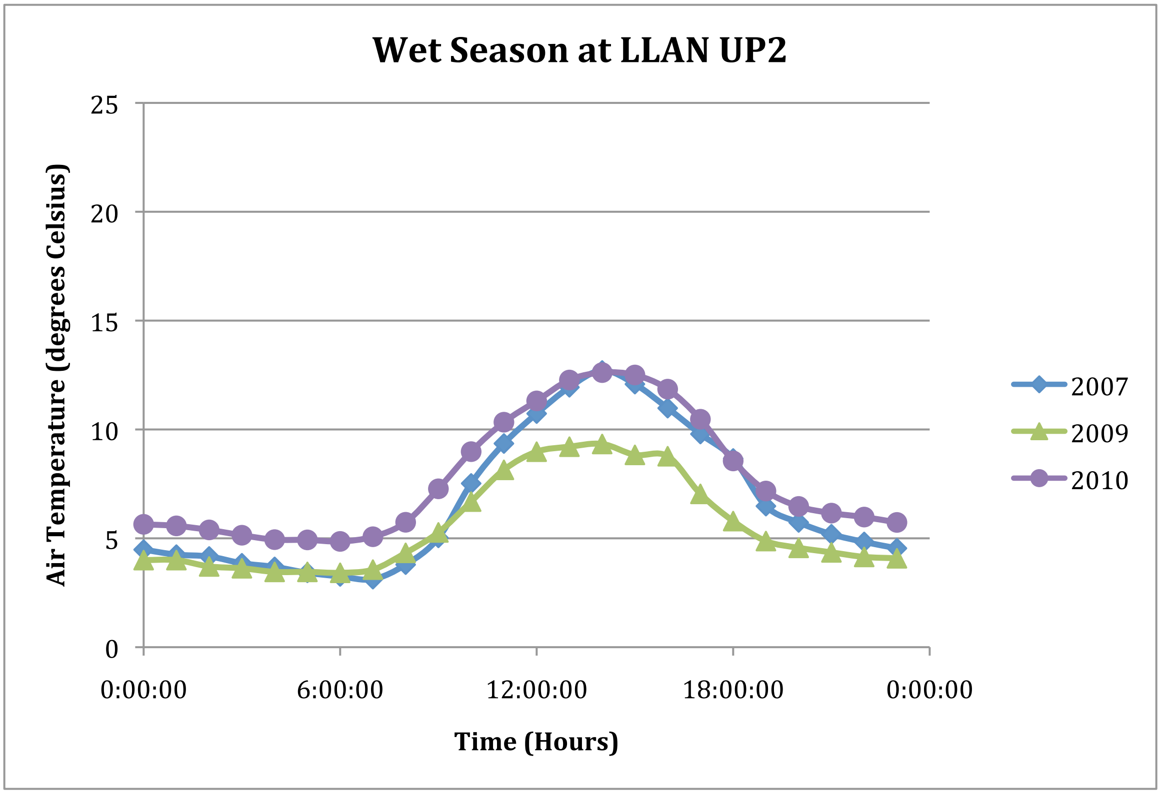


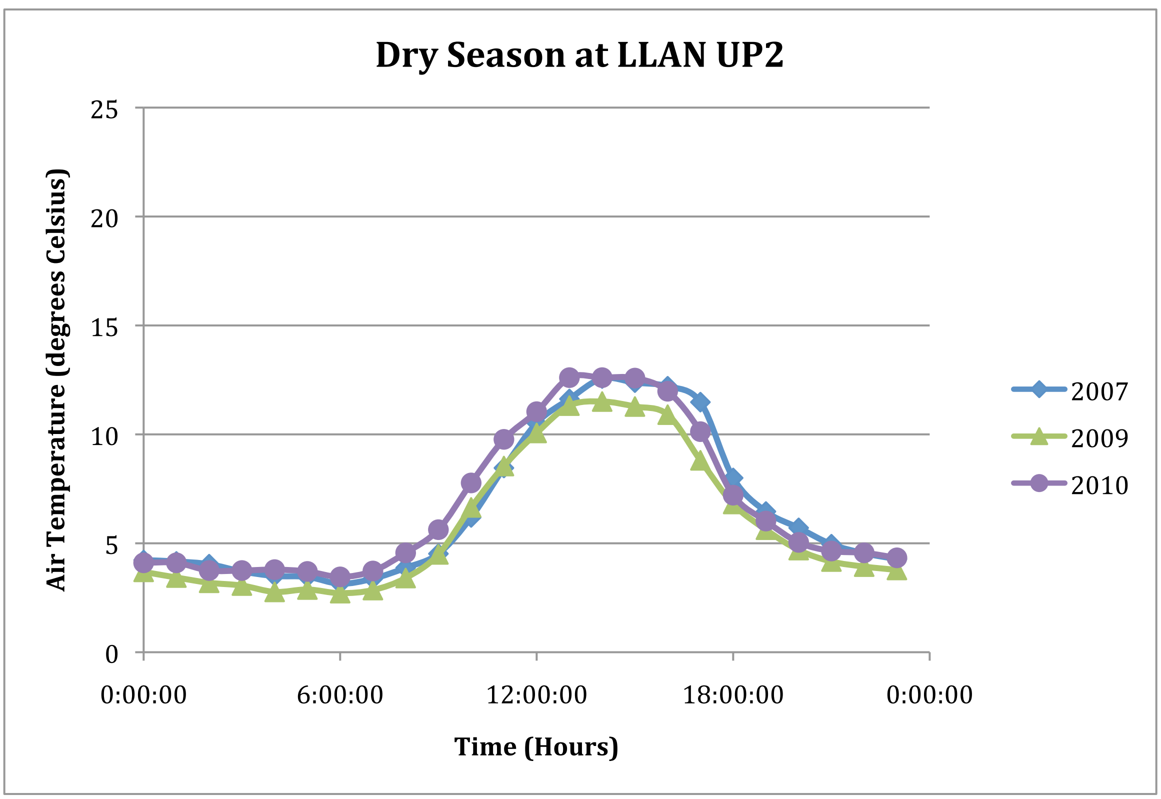

Wet Season at HOBO AWS
25
20
15
10
5
0
Air Temperature (degrees Celsius)
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2008
2009
2010

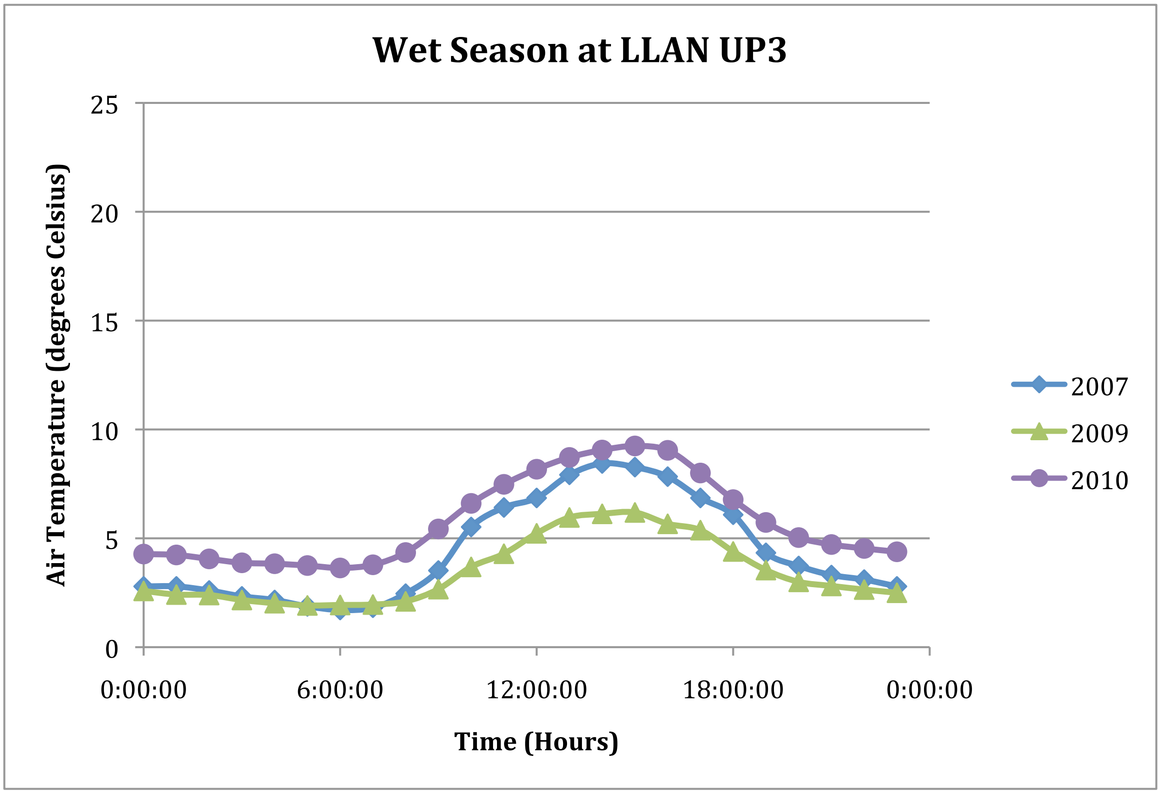

Dry Season at HOBO AWS
25
20
15
10
5
0
Air Temperature (degrees Celsius)
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2009
2010

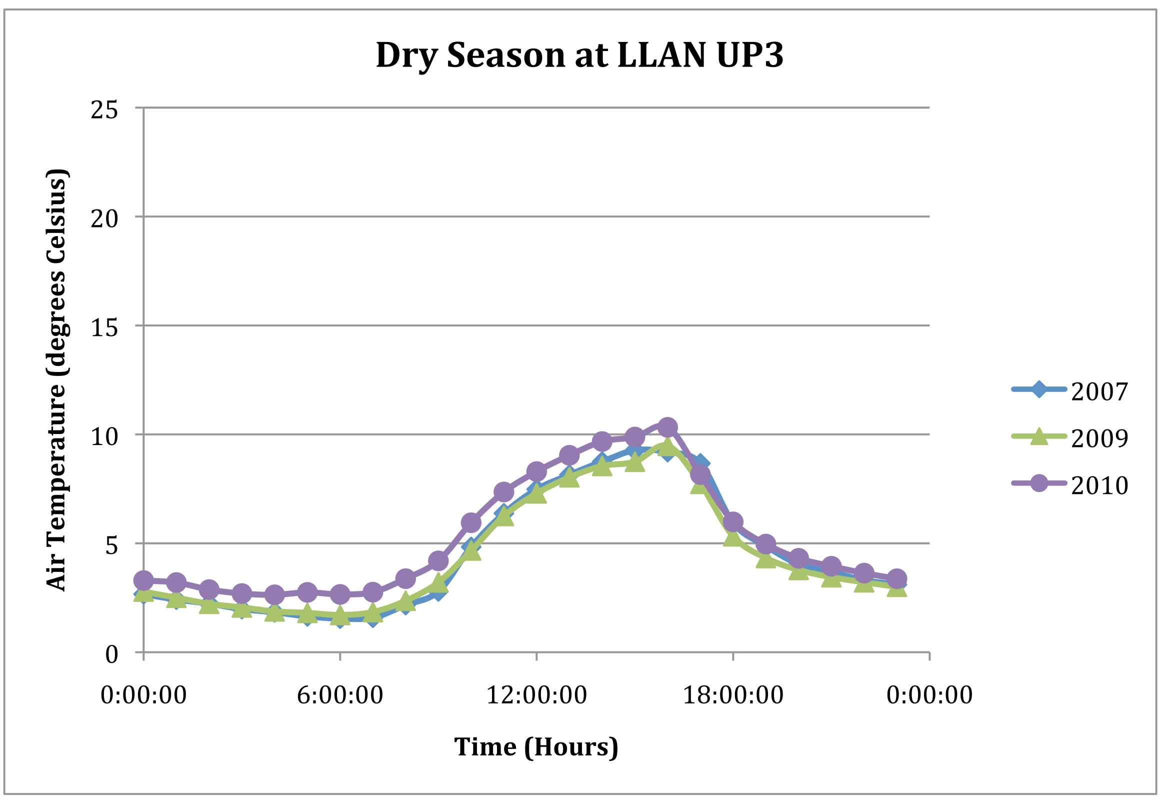

Wet Season at LLAN UP1
Air Temperature (degrees Celsius)
0
5
10
15
20
25
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2008
2009
2010

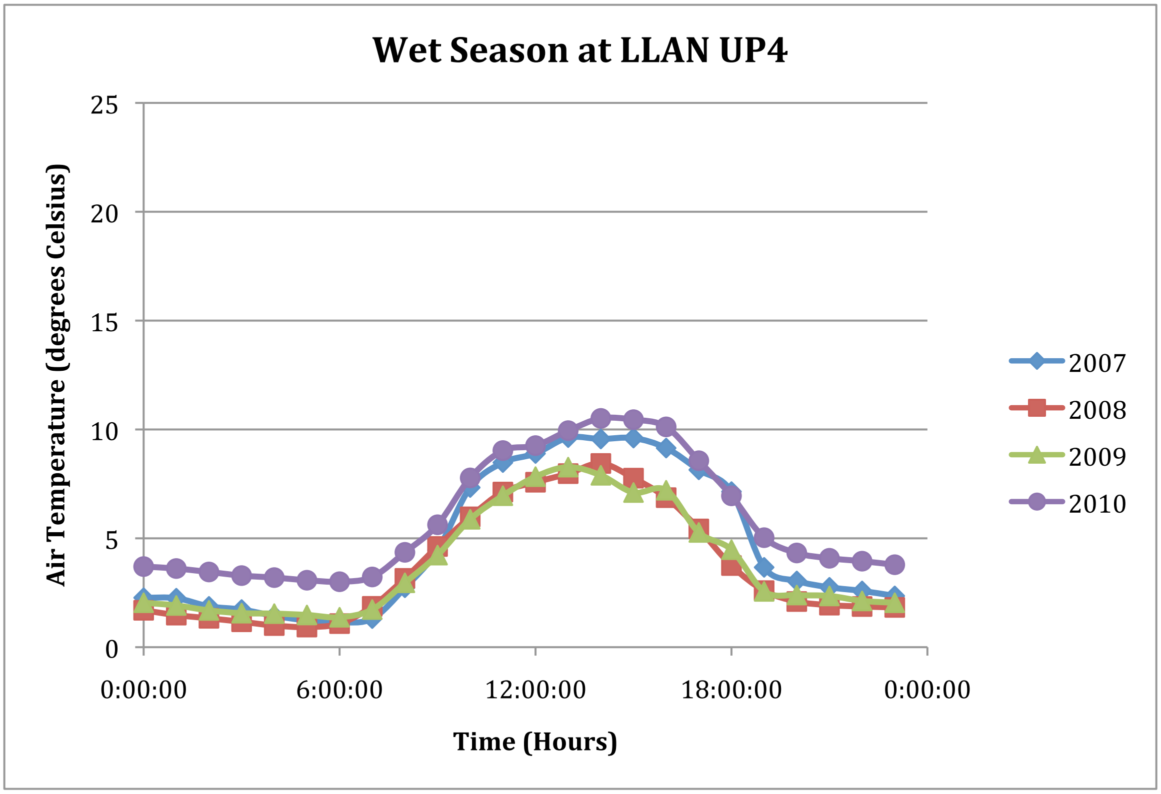

Dry Season at LLAN UP1
0
5
10
15
20
25
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
2007
2008
2009
2010


Wet Season at LLAN UP2
Air Temperature (degrees Celsius)
25
20
15
10
5
0
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2009
2010

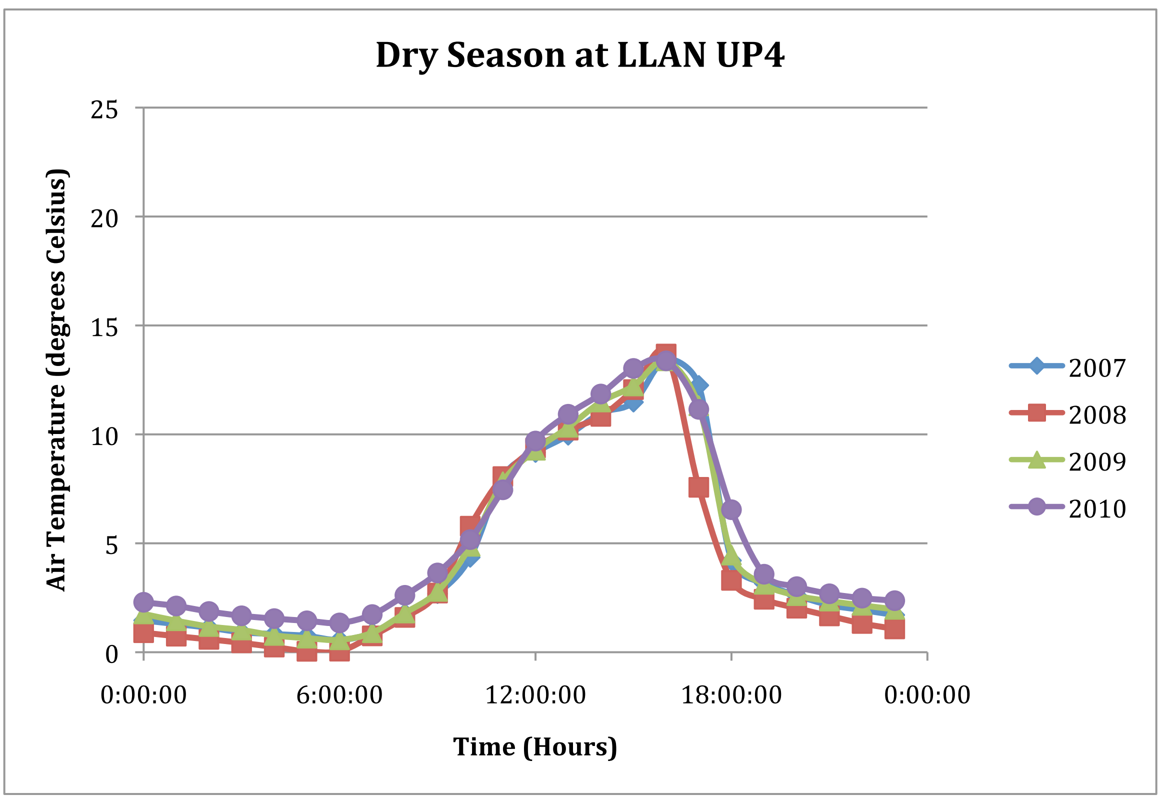

Dry Season at LLAN UP2
Air Temperature (degrees Celsius)
25
20
15
10
5
0
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2009
2010


Wet Season at LLAN UP3
Air Temperature (degrees Celsius)
25
20
15
10
5
0
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2009
2010

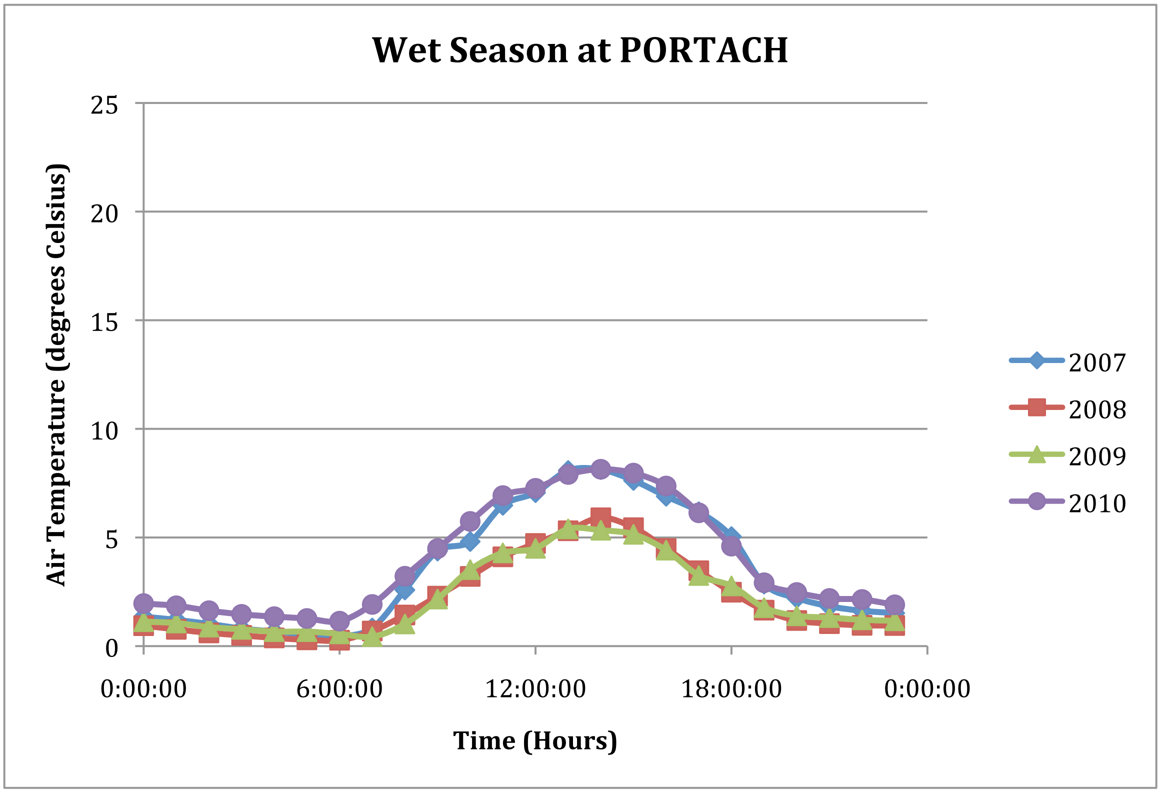

Dry Season at LLAN UP3
Air Temperature (degrees Celsius)
25
20
15
10
5
0
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2009
2010

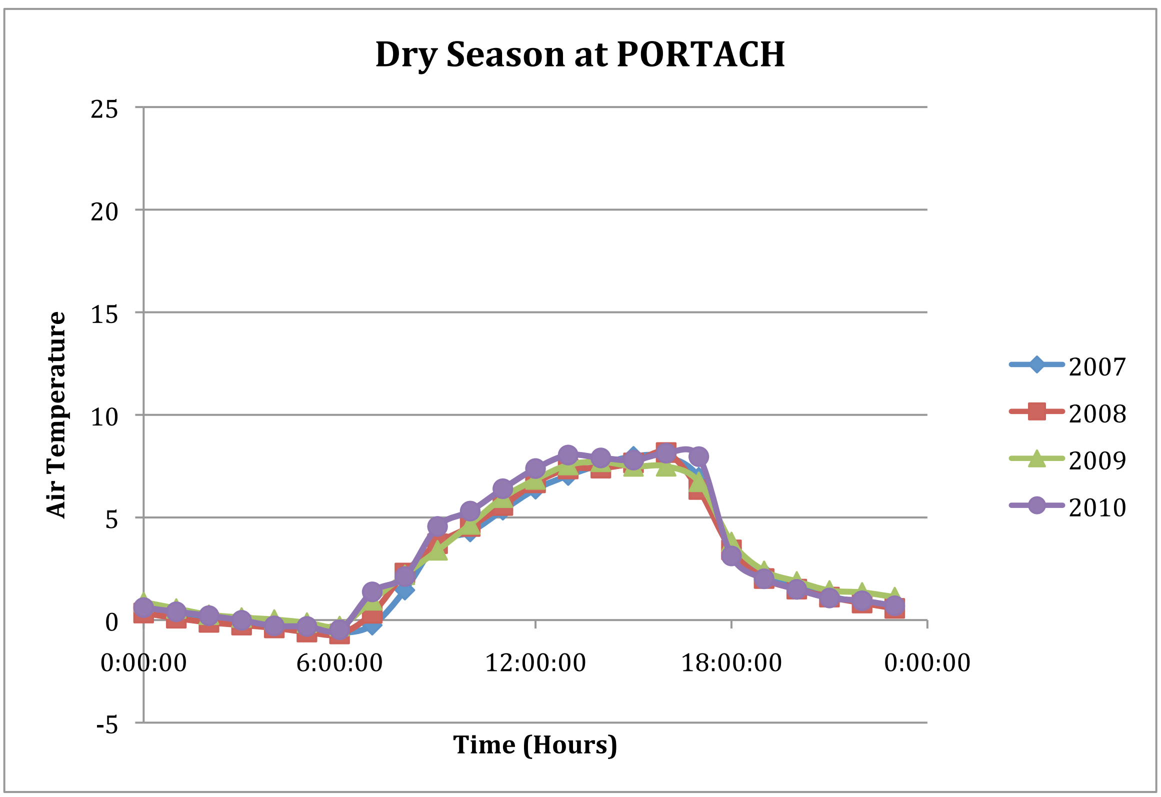


Wet Season at LLAN UP4
Air Temperature (degrees Celsius)
0
5
10
15
20
25
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2008
2009
2010



Dry Season at LLAN UP4
Air Temperature (degrees Celsius)
0
5
10
15
20
25
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2008
2009
2010


Wet Season at PORTACH
Air Temperature (degrees Celsius)
25
20
15
10
5
0
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2008
2009
2010


Dry Season at PORTACH
Air Temperature
25
20
15
10
5
0
-5
0:00:00
6:00:00
12:00:00
18:00:00
0:00:00
Time (Hours)
2007
2008
2009
2010